Intelligent Compaction Analyzer System for Vibratory Road Rollers using ARM Microcontroller and Data Updation on Server using Android Application

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Abstract - This paper provides an introduction to intelligent compaction for road construction and was developed as a resource for new users interested in understanding some of the applications and benefits of implementing this technology. Any agencies are into this business faced with the same challenges of reduced staff and having fewer people on site so more time and effort that is required for some of the quality assurance testing. It's just not available anymore, for that we need to find ways to accomplish with less staff time and may be the greater coverage of area because there is less number of knowledgeable people to do the inspection. One of our main aims to evolve away from the nuclear density gauges. We think that the natural evolvement for that would be the Intelligent Compaction Analyzer System.

Keywords- *Intelligent Compactor, IC, ICAS, FFT, Temperature, Android, Vibratory Rollers, Tandem, Soil,CMV,CCV*

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I. Introduction

Despite technology advance in other area of construction, earthwork compaction methods and equipment remains virtually the same as they were in the 1930s. The amount of compaction needed is based on a very imprecise measurement of the project sites compaction. Traditional testing methods add to the problem by measuring compaction every 1000+ feet. At best that's the hit and miss proposition. A further challenge is that traditional density moisture QA testing does not directly measure performance parameters of interest such as strength for stability control or stiffness issued in mechanistic pavement thickness design. Pavement layer stress causes cracks in the pavement are directly related to the uniformity and stiffness of the foundation materials.

Still one of the biggest things working with geotechnical section is really having a much better confidence of - what type of compaction?, where you have compaction out on a job site? With the ICAS, we have the potential of getting 100% coverage at least knowing where that roller has been versus traditional testing methods of density at certain points. This is a way we'll know - how many passes have been out on the job site?, where they have been?, where we might have trouble spots? That's probably the biggest thing that, we see as a benefit from our end of it is having that level of confidence, having more information and more comfort that we are getting from the compaction which we needed the most for the long-term pavements.

Quality compaction is important from so many different reasons that, we are building something for client and he's either going to build on it, pave on it or some type of construction after we're done. We make sure that, we're producing a quality product, so that we aren't creating a problem for our owner client down the road. We try to provide good foundation to start to build further on and with that good foundation it will improve everything from the bottom up.

Why do we have to go out and redo this road which was just built 3 years ago? Intelligent compaction technology in covering more of the actual final product and should be able to help us uncover in real-time, any anomalies are there, etc. Intelligent Compaction appears to be the solution, inspired by the prospect of great strides in construction efficiency and durability which would translate into millions in cost savings.

Recent research indicates that the intelligent compaction values correlates well with stiffness based in-situ test measurements such as the light weight deflectometer, plate load test and dynamic cone penetrometer. Stiffness based measurement that are rapid simple to perform are becoming more common and certainly intelligent compaction is going to play a role and providing a suitable alternative to traditional practices. In simple terms intelligent compaction is the integrated compaction measured position information and real time data processing and display. These measurement data relates to the engineering parameter values that are important for assessing quality. Intelligent compaction is already being built into roller equipment by several manufacturers, who are convinced of its high value. IC equipped rollers operated exactly the same way as traditional rollers. Operators do however require a few hours of instructions to become familiar with the IC monitor and aware how best to use the equipment to create the desired compaction. The use of IC also requires interpretation skills that mainly involve becoming familiar with the systems color coding and capabilities. These tasks are easy to master but do require some training.

II. Overview

Intelligent compaction technology, on the vibratory rollers along with Global Positioning System (GPS) to give the

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operator a real-time view of roller passes coverage and ground compaction/stiffness. The ICAS systems also can transmit the data to a remote location where it can also be monitored, saved and studied. Data is also saved on rollers on-board systems and can be downloaded for analysis. There are three approaches to determining IC measurements and are based on analysis of machine ground interactions.

Our version is based on frequency domain analysis (FFT) of accelerometer data and calculating the ratios of the amplitudes of the fundamental frequency and other harmonics. Another approach to use the accelerometer output to determine force-displacement responses using dynamic models. A third method is to monitor the machine power which is a function of drum sinkage and works for vibratory and non-vibratory operations. The IC values measured from these methods are an integrated response of the material stiffness under the roller to depths of approximately 1 to 3 feet. By instrumenting rollers with measurement technology, we can go for less than a 10th of a present to near 100%. Everywhere the roller goes we're getting information about the number of roller passes in that area, with GPS we're getting information of thickness and with the sensor system we're getting information of the ground compaction conditions.

The intelligent compaction monitor uses color coding to indicate compaction, which can be adjusted and correlated to independent engineering measurements. Here red area indicates the area of soil with low stiffness, yellow indicates the intermediate stiffness and green is high stiffness. Color scales can be set by performing independent measurements, correlation analysis and setting target values. In many ways IC makes compacting ground a little like painting with a roller brush. The operator can perform as many passes as required to get the desired level of compaction. The resulting data offers instant documentation of compactions. Inspectors can then more efficiently use their time to check problem areas.

III. Block Diagram

A. Soil Roller Compactor

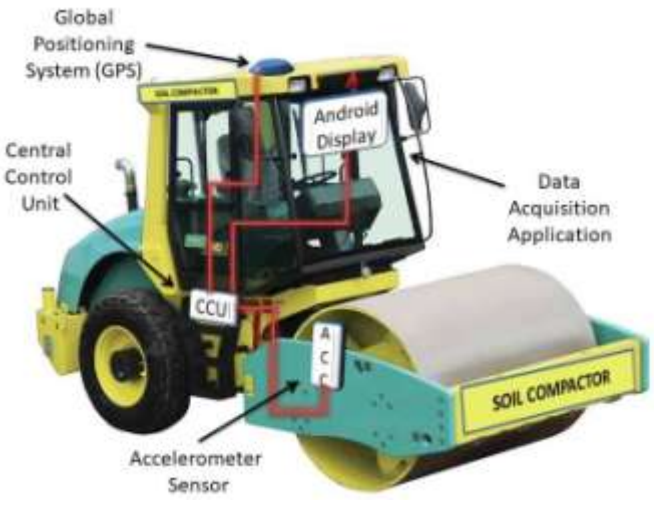

Figure (1): Soil Compactor – ICAS
(CCU, Accelerometer Sensor, Display, GPS)

B. Tandem Roller Compactors

Figure (2): Tandem Compactor – ICAS
(CCU, Front & Rare Accelerometer Sensor, IR Temperature Sensor Display, GPS)

IV. Methodolgy

We have two types of compactor models i.e. Soil Compactor (for soil/land compaction) and other one is Tandem Compactor (for bituminous compaction), both are having the similar setup i.e. accelerometer sensors for detection of vibration, central control unit for data acquisition from sensors and vibration analysis, android based application for rollers operators, global positioning system (GPS). Tandem roller have one extra sensor i.e. temperature sensor for recording the temperature of laid bituminous material.

The important aspect of ICAS is detection of vibrations created by the roller drums, analyzes them and shows the real time analysis report. The Compaction Meter Value (CMV), Compaction Control Value (CCV) & Resonant Meter Value (RMV) are the measurement parameters determined by this analysis and they represent the stiffness or compactness of the surface. We need something to rely on, by which we can finalize the result that the land is well compacted and further construction work can be performed. These parameters are completely based on the frequency domain analysis (FFT) of the real-time vibration signals coming from different permutation combination of amplitude, frequency and speed setting of the vibratory rollers.

A. Compaction Meter Value (CMV)

Compaction meter value (CMV) depends on rolleroperation parameters (i.e. frequency, amplitude, speed), and is determined using the real-time roller response, recorded by using accelerometer sensor. The calculation performed on harmoniccomponents of drum vibration with increasing ground stiffness is illustrated in figure 3. CMVis calculated using Eq. 1, where C is a constant (300), $A2\Omega$is the acceleration of the firstharmonic component of the vibration and $A\Omega$= the acceleration of the fundamental component ofthe vibration.

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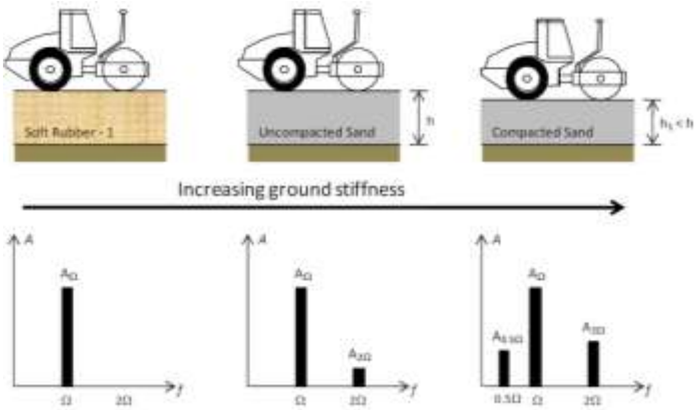
$$CMV = C \cdot \frac{A_{2\Omega}}{A_{\Omega}} \quad \ldots (1)$$

B. Resonant Meter Value (RMV)

The system can also measures the resonant meter value (RMV) which provides anindication of behaviour of drum i.e. continuous contact, partial uplift, double jump, rockingmotion, chaotic motion and is calculated using Eq. 2, where A0.5Ω= sub-harmonicacceleration amplitude caused by jumping drum (Figure 3). It is very important to note that thebehaviour of drum might affects the CMV therefore RMV must be taken into consideration for better result. It is also called as Bouncing Value (BV).

$$RMV \text{ or } BV = C \cdot \frac{A_{0.5\Omega}}{A_{\Omega}} \quad \ldots (2)$$



Figure(3): Illustration of changes in drum harmonics with increasing ground stiffness

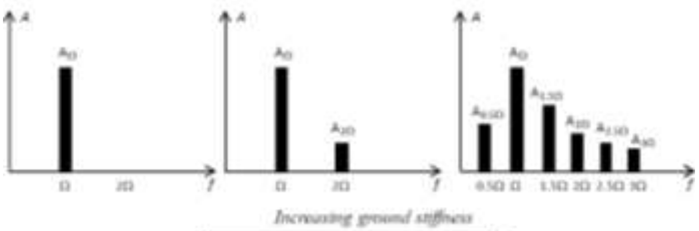


Figure (4): Change in amplitude spectrum with increase in ground stiffness

C. Compaction Control Value (CCV)

The CCV determination tends towards more precision. It is more precise than CMV as it uses the acceleration data from the A0.5Ω, AΩ, and more higher-order harmonics i.e. 1.5Ω, 2Ω, 2.5Ω, 3Ω into account as shown in Eq. 3. Sakai rollerresearchersfound that as the ground stiffness increases and theroller drum enters into a jumping motion, vibration accelerations at various frequencycomponents are developed as illustrated in Figure 4.

$$CCV = \left[\frac{A_{0.5\Omega} + A_{1.5\Omega} + A_{2\Omega} + A_{2.5\Omega} + A_{3\Omega}}{A_{0.5\Omega} + A_{\Omega}}\right] \times 100 \quad \ldots (3)$$

D. Roller Drum Behavour

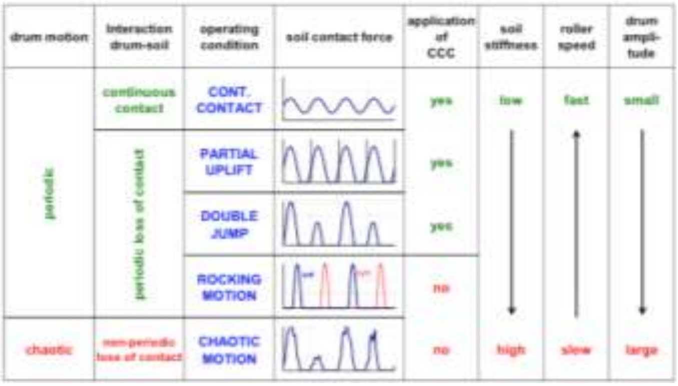


Figure (5): Roller Drum Behaviour depends on Soil Stiffness

Here we consider the collaborative results given by CMV, CCV & RMV for taking the decision on where the material is compacted or not or yet to be compacted are perform more operations. The values of CMV, CCV we consider into percentage. Investigations performed on roller i.e. calculating the values for drum-soil interaction provides us the five different drum behavior which are dependent on the soil stiffness and roller operational settings (i.e., amplitude, frequency, and speed). These five modes are viz. 1) Continuous contact, 2) Partial up-lift 3) Double jump 4) Rocking motion 5) Chaotic motion as shown in Figure (5).

Also, the graph shown in figure (6) defines the values of CMV /CCV depending on the roller drum behavior with increasing material/soil stiffness. For CMV/CCV measurement technology the drum jumping behavior is examined by the RMV measurements i.e. RMV = 0 indicates - drum is in a continuous contact or partial uplift mode. RMV > 0 indicates - drum enters double jump mode and then further transitions into rocking and chaotic modes with increasing soil stiffness.

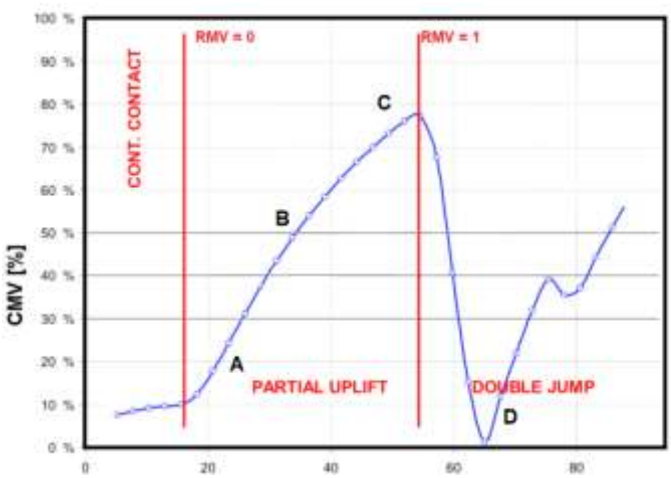


Figure (6): Representation of CMV(CCV)with respect to drum behavior

The transition in the CMV depends upon the compaction capacity of the material. It means that, at point A, the material is loosely compacted, so it has the capacity of more compaction. It has the gaps and loosely bounded particles so, it has chance for more compaction. Further at point B, the compaction reached at the optimal level, where the quality of material is good and the level of compaction is moderate. But we consider this moderate compaction is the ideal one, as the material can able to breath and can handle the vibration created by the other factors, such as heavy load vehicles, construction works, etc. But without considering the optimal compaction if more compaction can be done, then the material reach its breaking point i.e. point C. This point we call it as an over compaction. This over compaction results into the breaking of the innermost layer of mater so as to make more space for compaction. If the over compaction is done, then it results into the loosening of material again and it will reach to point D, from where the new material has to be added as the old material got damaged and need to perform compaction again with new material so as to reach the ideal level of compaction again.

E. Fast Forier Transform

FFT is performed on the acquired vibration signals to convert them from time domain to frequency domain as to meet the calculation requirement, i.e. the Amplitudes of the fundamental frequency i.e. AΩ and its harmonics i.e. A0.5Ω, A2Ω, A3Ω, A4Ω, etc. With the help of FFT we are able to calculate CMV, CCV, RMV, Vibrating Frequency of roller drum, Displacement performed by roller drum i.e. drum amplitude.

V. Hardware / Major Components

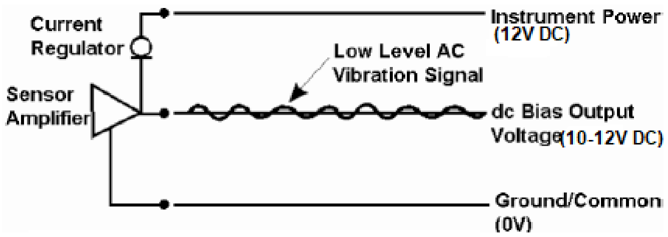
As shown in figure (1) and (2), there are two types of vibratory roller compactors i.e. soil and tandem, and they have 2 small differencesthat,Tandem compactor having one extra accelerometer sensor and a temperature sensor. The description of all the main components, modules and sensors are as follows.

A. Control Central Unit

Control central unit consist of anembedded circuit board. The circuit board consists of ARM DSP Microcontroller, Signal Conditioner Circuit for accelerometer sensor, temperature sensor & data ports for getting navigational data from GPS module (i.e. Latitude, Longitude, Speed, Course) and sending all the analyzed and calculated data to MDT (Mobile Display Terminal) i.e. on Android app for roller operator.

B. Accelerometer Sensor

Sensors are made up of piezo-electric material which is very sensitive to vibrations. The types of sensors depends on their output ratings i.e. 100mV/g, 500mV/g, 1000mV/g, etc. These two wire sensors have specific electrical requirement. It needs 10-12V DC as a biased voltage. Also, it requires only 2-10mA current. When both the conditions are fulfilled, then the output of the vibration is travel back i.e. it can be extracted from the supply 12V biased line as the output signals are superimposed on it as shown in figure (7).



Figure(7): Sensor Signal Extraction Setup

We place this sensor on the vibratory roller drum as shown in figure (1) & (2), so as to detect its vibrations and send it to the CCU for further analysis. In general, these sensors are designed for monitoring areas with limitedspace. The general purpose accelerometer is ideal for monitoring machine vibration on a widerange of rotating equipment such as motors, pumps, fans, compressors, turbines and generators.

C. Infrared Temperature Sensor

It isa non-contact temperature sensor. It calculates the surface temperature depending on the infrared energy emitted by the object. Depending upon the surface temperature each object radiated infrared radiations. Thus change in temperature results into change in radiation. For measurement of these thermal radiations, the thermometer uses a wave-length raging between 1µ and 20µm.

Infrared sensors are also known as optoelectronic sensor. The most important feature of this sensor is contactless. This helps us to measure the temperature of inaccessible or even moving objects without any difficulty. It has the spectral filter and selectable wavelength range. It has the variable voltage output range along with the variable input temperature range.

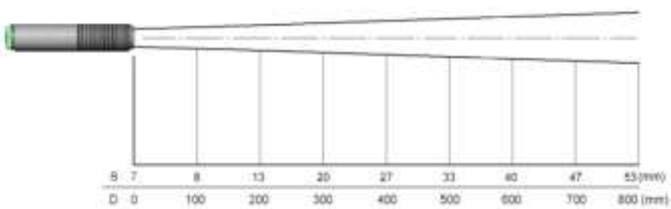


Figure (8): Optical Diameter Chart

Figure (8)show the diameter of the measuring spot, depends on the distance between measuring object and sensor. The spot size refers to 90 % of the radiation energy. The distance is always measured from the front edge of the sensor housing.

D. Global Positioning System (GPS)

GPS uses satellite data for accurately calculating the position on earth. These calculations shows user's position in the form of Latitude and Longitude

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and can be located using any map projection in notime. There are ranges of modules present in the market and they work very similar to each other. But, they have the most significant difference is the accuracy which totally depends upon the number of satellites they can simultaneously communicate with. More the number of satellites, more the correction factor tend towards accurate values. This accuracy helps us to find not only the position of the user but also the course it is heading to, speed, real time, etc.

E. Android Appication

An android tablet is used for displaying the real-time compaction parameters to the roller operator. Depending upon the compaction values we have provided the color mapping also, which gives the roller operator a visualizing idea of where he have to do more for compacting the surface. The android application, in front end,shows data to operator, but in back end it creates a local data base as well as it upload that real-time data to our server using 2G/3G/4G mobile data. This will help us to maintain the data of work done; also we use data for further analysis ifrequired. We have 3 versions of the android application viz.

i) Soil Compactor – For 1 Accelerometer Senor
ii) Tandem Compactor – For 1 Accelerometer Senor & 1 Temperature Sensor
iii) Tandem Compactor – For 2 Accelerometer Sensors& 2 Temperature Sensors

Figure (9): Soil Compactor – For 1 Accelerometer Senor

Figure (10): Tandem Compactor – For 1 Accelerometer Senor & 1 Temperature Sensor

Figure (11): Tandem Compactor – For 2 Accelerometer Sensors & 2 Temperature Sensors

VI. Standard Values vs Practicle Results

Depending upon the surface and material type, there are some standard values are given for drum's vibrating frequencies and the tentative required CMV/CCV values by the public work department. The natural frequencies of sand varies in between 24-29Hz, it depends on particle size and moisture percentage. For clay it is 28-30Hz & for rocks its 29-30 approximately. The expected CMV/CCV values are divided into four categories i.e. for clay & slit it is in between 5-10, for sand it varies in between 20-50, for gravels and rock fill it fluctuates between 30-80 and 60-100 respectively.

As compared to the standard values, we tested our system on different makes of vibratory rollers. Their drum frequency ranges from 15-40 Hz. Depending upon the material type we have received the values in following range i.e. for clay & slit it is in between 2-8, for sand it varies in between 15-35, for gravels and rock fill it fluctuates between 25-55 and 35-65 respectively. We also have the bituminous material, as it is like clay like property at the beginning, but after that as it goes on cooling it starts becoming solid i.e. slit or sand like material but a bit viscous in nature and finally it become rock solid. So for this material we have got gradual increase in the CMV/CCV values.

VII. Conclusion

According to figure (6), bituminous material shows gradual increase in the CMV values i.e. it starts from nearly 10-15 and then gradually rises up and reached point B, which we consider as an optimum level for compaction of the material. We have used a target value setting in our android application i.e. to avoid over compaction, which results into the degradation of the surface. Also, we have used relative colour patternsfor ground stiffness to reduce the number of passes, which automatically results into following advantages:

i) Lessening time for compaction work
ii) Lessening efforts of operator
iii) Lessening fuel consumption
iv) Perfect and Durable Compaction.

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